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Reply on “Eel River margin source-to-sink sediment budgets: Revisited” by J.A. Warrick [Marine Geology 351(2014) 25–37]

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I thank Drs. Sommerfield and Nittrouer for their interest in my work on sediment discharge from coastal rivers of northern California. Their letter raised several questions and doubts about the data and analyses used in my recent paper published in Marine Geology (Warrick, 2014a). Before addressing these points, it is important to restate some findings that remain undisputed:

- The geomorphic conditions of the Eel River and surrounding watersheds clearly reveal massive increases in sediment supplies during the mid-20th century and steady decreases in the following decades (e.g., Kelsey, 1980; Lisle, 1982; Nolan and Janda, 1995; Madej and Ozaki, 1996, 2009; and references cited in Section 1 of Warrick (2014a) and Sections 1, 2 and 6 of Warrick et al. (2013)).
- All coastal watersheds of northern California with suspended-sediment sampling data show coherent temporal patterns in suspended-sediment concentrations with respect to discharge, including concentration increases during the 1965 water year and subsequent decreases to the present day (Anderson, 1970; Brown and Ritter, 1971; Brown, 1973; Knott, 1974; Kelsey, 1980; Klein and Anderson, 2012; Warrick et al., 2013).
- Recent work by Wheatcroft et al. (2013) on the Umpqua River-dominated shelf immediately north of the Eel River study area suggests that much of this shelf shows, “… *a 2–4-fold increase in the (sediment accumulation rates) that … is consistent with the history of industrial logging … and coincided with a wet phase of the Pacific Decadal Oscillation* …” [quoted from their Abstract]
- Sedimentation rates for the Eel River-dominated shelf increased markedly between the early and middle 20th century and then decreased significantly during the latter 20th century (see Fig. 4 in Sommerfield et al. (2002) or Fig. 14 in Warrick et al. (2013)).

Thus, if the primary assertion of Sommerfield and Nittrouer's (2014–in this issue) Comment letter—that Eel River sediment load relationships have been stationary with time—is correct, and by implication that these sediment loads were not overestimated in their former work that used simple, stationary sediment-supply models, then their Comment letter is inconsistent with a broad body of the scientific literature.

Irrespective of this issue of scientific consistency, I will show here that Sommerfield and Nittrouer's (2014–in this issue) assertions are incorrect based on published sections of work in Warrick (2014a). I do not assume that these sections were overlooked or ignored by the commenting authors, but rather that I may not have communicated them clearly. Thus, I repeat a number of the techniques and findings from Warrick (2014a) and their implications:

- The potential for sampling bias was real and analyzed in detail in Warrick (2014a). As noted by Sommerfield and Nittrouer (2014–in this issue), the greatest potential for bias occurs with an alteration of the sampling program strategy. These kinds of biases were identified in Sections 2.1.1 and 3.2 of Warrick (2014a), where, for example, it was noted that, “… *sampling strategies have changed with time, especially after 1980 when somewhat regular bimonthly samples were added to the sampling schedules to better characterize water quality conditions of the Eel River*.” [p. 28]
  To address the potential problems introduced by these sampling biases, many standard analysis techniques were used in Warrick (2014a). For example, the weighted-regression techniques of Hirsch et al. (2010) were used with the daily 1960–1980 data to evaluate suspended-sediment concentrations independent of the discharge values sampled and measured (see Section 3.1 and Fig. 5d in Warrick, 2014a). Also, evaluation of the post-1980 trends included removal of the new sample types, i.e., those taken during the summer and low flows (see Section 3.2 in Warrick, 2014a). The remaining samples were then analyzed graphically (see Fig. 6 in Warrick, 2014a) and statistically (see Figs. 7 and 10d,e in Warrick, 2014a), consistent with suggestions from Helsel and Hirsch (2002). Furthermore, the “grab” samples collected during high flow conditions by Geyer et al. (2000) and Goñi et al. (2013) were evaluated and found to be adequate surrogates for fine-grained (<0.063 mm) suspended-sediment concentrations (see Part I of the Supplemental Information for Warrick, 2014a). In fact, careful readers will be able to see how this treatment incorporates conservative results into the computations of sediment concentration trends, owing to the assumption that the grab samples were entirely fine-grained (hint: the grab samples also contained some sand). Combined, these techniques and results universally pointed toward unsteady relationships between river discharge and suspended-sediment concentrations independent of sampling biases (e.g., see Figs. 4, 5, 6, 7 and 10 in Warrick (2014a)). That is, the changes in sediment concentrations reported in Warrick (2014a) and used for revised sediment budgets cannot be explained by changes in sampling program. Furthermore,

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the changes in sediment concentrations for the Eel River are consistent with other rivers of the region, like Redwood Creek, which do not have similar sampling program changes and have been sampled consistently for high flow conditions over time (cf. Fig. 6e in Warrick et al. (2013)).

- The former Mad River sediment loads computed by Sommerfield et al. (2007) were not "accepted" in Warrick (2014a). Rather, it was assumed that the time-dependent patterns that existed in the Eel River also existed in the Mad River. This is consistent with the broad-scale sediment production patterns exhibited in the region that were noted above and in Warrick et al. (2013). A constant scaling between the two river's loads—such as used in Warrick (2014a)—would force this time-dependency.
- Both measured instantaneous and estimated daily average suspended-sediment concentrations are suitable for trend analyses and load estimates. For other examples of the use of both kinds of samples in my work, please see Warrick and Rubin (2007), Warrick et al. (2013), and Warrick (2014b), the latter of which includes additional observations from the Eel River. For a thorough discussion of these topics, readers are directed to Helsel and Hirsch (2002).
- The logic behind the Warrick (2014a) paper was: (i) time-dependent trends were analyzed and found to exist, (ii) these trends were consistent with a large body of geomorphic literature for the study area, and thus (iii) the time-dependent trends could be extrapolated to intra-years that did not have sampling data by use of simple trend models and to pre-sampling years assuming a broad range of sediment source terms based on available data. No attempt was made to derive time-dependent trends from land-use or extreme-flow patterns or relationships as suggested by Sommerfield and Nittrouer (2014–in this issue).

In conclusion, the comments and concerns of Sommerfield and Nittrouer (2014–in this issue) were fully addressed in the original Warrick (2014a) paper and have no critical basis on the results presented therein. In contrast to the presentation of Sommerfield and Nittrouer (2014–in this issue) sediment discharge from coastal northern California watersheds have been non-stationary for at least the past 60–70 years as exhibited in landscape and fluvial geomorphology, hydrological records, and continental shelf sedimentation rates. The best source of the "unaccounted" sediment in the Eel River margin budget developed by Sommerfield et al. (2007) is, therefore, their overestimation of river sediment discharge by using a stationary sediment-rating curve.

In lieu of this, I was glad to see Sommerfield and Nittrouer (2014–in this issue) correct their long-standing confusion between USGS measured concentration data and USGS estimated daily concentration data, which unfortunately permeated the results and publications of the STRATAFORM project. While these sampling and data topics are somewhat complex, they are described and referenced in numerous publications, including my own (e.g., Warrick and Milliman, 2003; Warrick and Rubin, 2007; Warrick and Mertes, 2009; Warrick et al., 2013; Warrick, 2014a) and many others (e.g., Glysson, 1987; Edwards and Glysson, 1999; Gray and Simões, 2008; Gray and Landers, 2013). For further information and thorough lists of reports about these topics, readers are directed toward: [http://water.usgs.gov/osw/techniques/sediment.html], and [http://pubs.usgs.gov/twri/].

I look forward to further developments and progress toward understanding the sources, transport and sinks of sediment along continental margins. The groundbreaking work conducted at the Eel River margin through STRATAFORM and related projects will stand as an important—if not the best—body of research on these topics for decades to come. Although previous Eel River researchers chose good and defendable methods, their assumptions of stationary river sediment production relationships turned out to be invalid. Hence, reevaluation of the margin sediment budget—such as was conducted by Warrick (2014a)—is required.

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